

Overview of Intelligent Power Controller Development for the Deep Space Gateway

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Presented to Energy Tech 2017 Cleveland, Ohio









Agenda

- Overview of NASA Vision
- Deep Space Exploration
- The Autonomous Power Control Concept
- Autonomous Power Control Development
- Verification
- Applicability to Hybrid-Electric Propulsion

Exploring Space In Partnership

and when lunar

resources are available

2030s Leaving the Earth-**Moon System and** 2020s **Reaching Mars** Advancing technologies, discovery and creating economic opportunities Operating in the **Orbit** Now **Using the** International **Space Station** Phase 0 Phase 1 Phase 2 Phases 3 and 4 Solve exploration **Conduct missions** Complete Deep Missions to the mission challenges in cislunar space; **Space Transport** Mars system, the through research and assemble Deep and conduct Mars surface of Mars systems testing on **Space Gateway and** verification mission the ISS. Understand if **Deep Space**

Transport

The Future of Exploration

100s

of Miles



100,000,000s

of Miles

		4.		
•	Commun	ication	becomes a	problem

1,000s

of Miles

- Bandwidth is factor of less than 100 of ISS
- Times are longer than any previous experience

10,000s

of Miles

International Space Station	Moon	Mars
Mission	Communication Bandwidth	Communication Latency
ISS	300-800 Mbps (TDRS)	Real-time
Apollo / Orion	<2 Mbps (DSN)	1 to 2 seconds
Deep Space Vehicle	<2 Mbps (DSN)	15 to 45 minutes

100,000s

of Miles

1,000,000s

of Miles

10,000,000s

of Miles

130 t

Power is required to operate all subsystems on the vehicle.

Human Space (

Human Space I

Earth

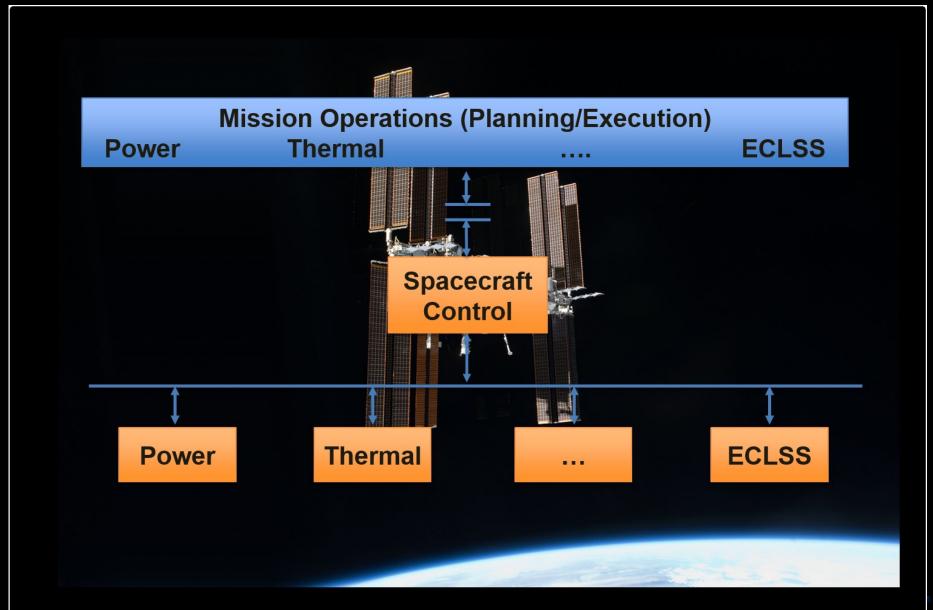
- Highly reliable
- Power system must operate autonomously.

Robotic Science

www.nasa.gov/sls



Typical Spacecraft Control Architecture

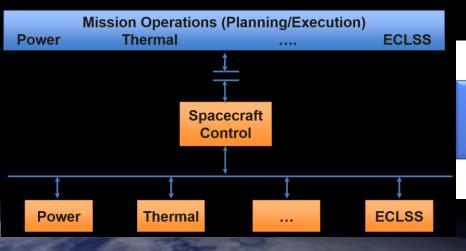


Traditional vs Autonomous Spacecraft Controller

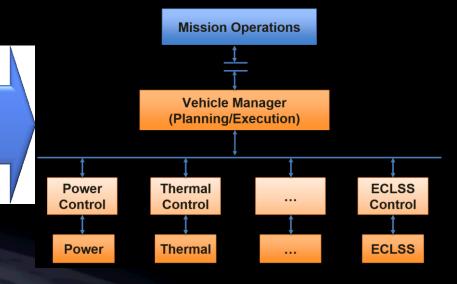


Transition ground based control functions to the vehicle

Traditional Spacecraft Controller Architecture



Autonomous Spacecraft Controller Architecture



Vehicle Autonomous Power Control Architecture



Mission Operations

- Monitors vehicle operations.
- Adjusts long term mission objectives.

Vehicle Manager

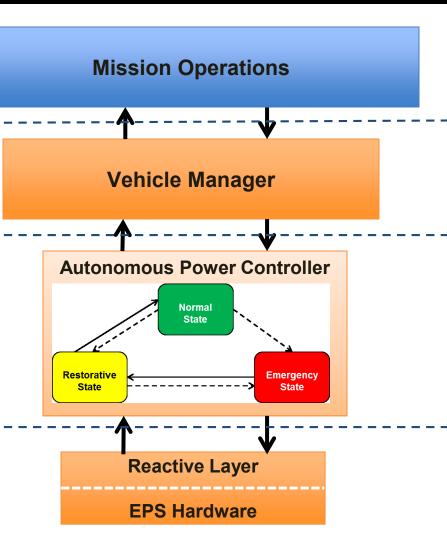
- Plan vehicle operation(s) to achieve mission objectives (e.g. Load Schedules).
- · Coordinate vehicle subsystems.

Autonomous Power Controller

- Forecast energy availability and provide power to the highest priority loads.
- Safely operate the EPS hardware.

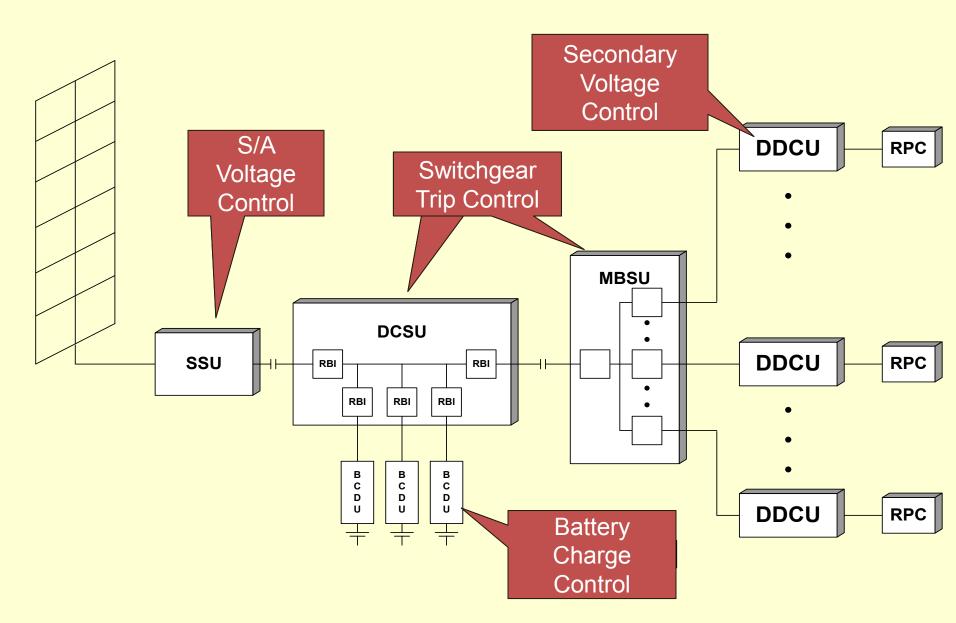
Reactive Layer (Full Digital Control)

- Provides closed-loop control of the EPS hardware.
- Protect EPS from hard faults (safe the system).



Power System Reactive Layer Controller





APC Normal Mode Functions

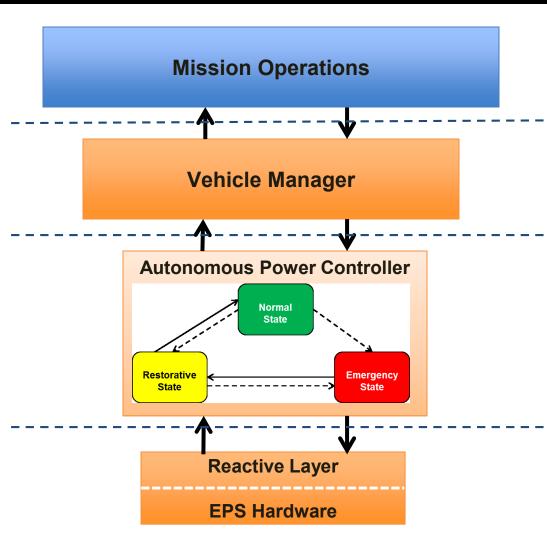


Coordinate with Vehicle Manager

- Predicts power availability
- Develop a workable load schedule
- Executes load schedule

Safely Operate EPS

- Optimizes energy utilization and distribution system utilization
- Receives data and sends configuration information to the reactive layer control
- Continuously monitors for faults within the EPS



APC Failure Mode Functions

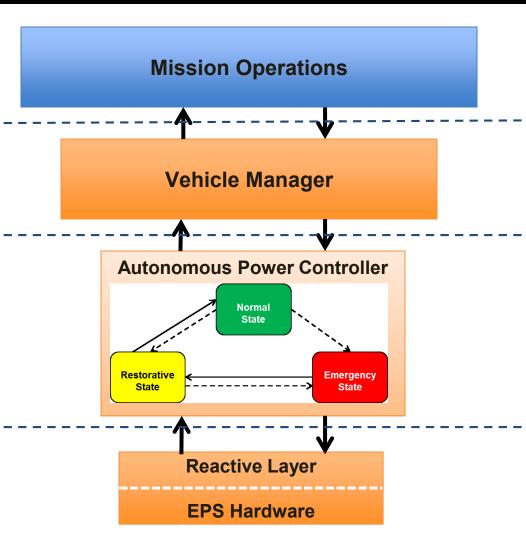


APC Response

- Safe the system (hard faults) and Identifies and reacts to other soft faults
- Develops recovery plans to optimize the servicing of the remaining loads
- Develop recovery plan
- Reports "Emergency State" to the Vehicle Manager

Vehicle Response

- VM develops restoration schedule based on fault information
- APC Executes the restoration schedule





Autonomous Power Controller Development and Configuration



APC Controller Architecture



Contingency Planner

- Develop new system configuration based on system state
- Initiate energy manager to develop new power availability
- Develop load shed table based on priorities

Reactive Layer (hardware)

- Provide power system data
- Execute set points (turn loads on and off)
- Safe hardware (automatic fault protection)

Vehicle Manager Database

Energy Manager

- Calculate battery state of charge
- Develop the power availability profile
- Evaluate load schedule for issues
- Optimize battery state of charge across the vehicle

Fault Manager

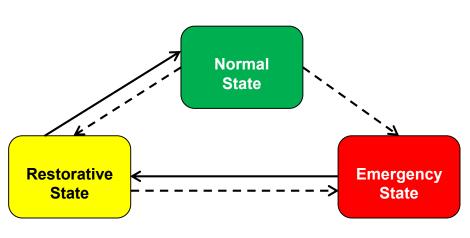
- Detect and respond to faults
- Active model testing of sensed data
- Sensor state estimator

APC Executioner

- Initiate energy manager to create power availability profile
- · Initiate energy manager to evaluate load schedule
- Check/validate fault detected by fault manager (expert system function)
- Request/dispatch a contingency plan
- · Request/dispatch a recovery plan
- Update system configuration based on contingency planner
- Notify VM of configuration update, request new schedule
- Respond to requests from VM for power availability and load schedule eval
- Notify VM of fault

Autonomous Control State Diagram





Controlled State Transition

Uncontrolled State Transition

Normal State:

- Operating properly
- Provides an energy availability and power profile
- Analyzes proposed load schedules
- With no failures, the APC could continue in the state indefinitely.

Emergency State:

- Failure has occurred in the EPS
- Reactive control will respond to any immediate faults and temporarily put the system in safe mode.
- APC reconfigures the system

Restorative State:

- System is in a reduced power state and may not be servicing the complete normal load
- APC can perform all the operations of the normal state, with reduced power constraints.

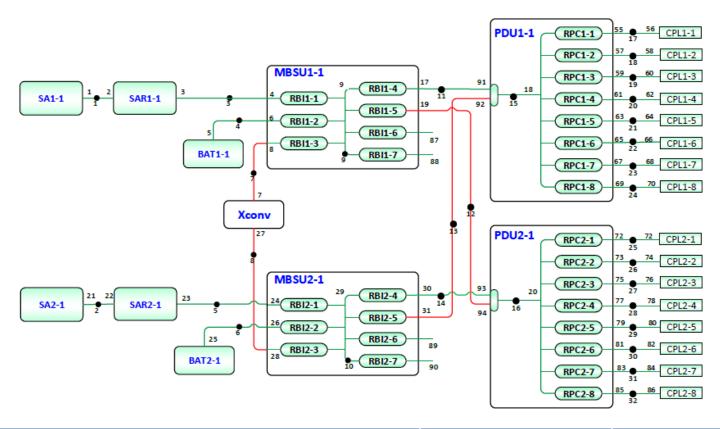


Autonomous Power Controller Verification Approach



EPS 2-String System Architecture





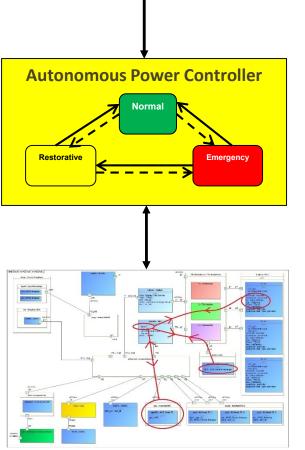
Power System Ratings	Peak	Nominal
RPC Current Rating (Amps)	4	3.2
RPC Power Rating @ 120V (kW)	0.48	0.384
PDU Current Rating (Amps)	32	24
PDU Power Rating @ 120V (kW)	3.84	2.88
Total Power to Loads (kW)	7.68	5.76 15

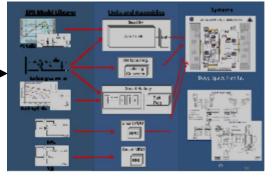
Test and Evaluation Approach





GRC Deep Space Vehicle Power System Test Bed



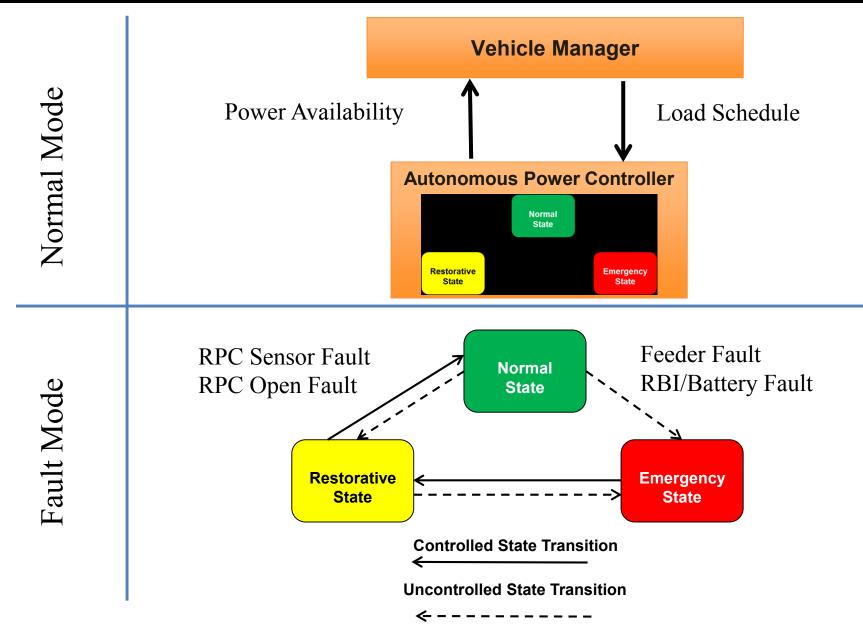


GRC Real Time Simulation

JSC iPAS Test Bed

Demonstrations

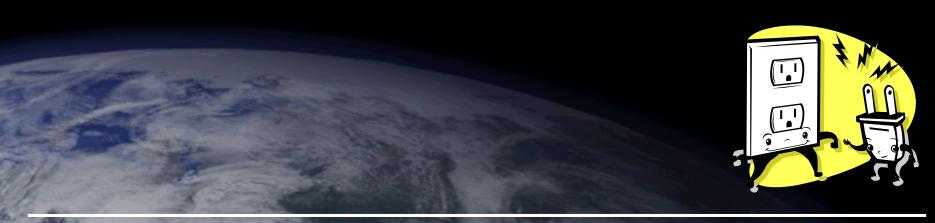








Extensions to Hybrid Electric Propulsion





Hybrid Electric Aircraft

Hybrid Electric Aircraft have very similar needs to space vehicle power systems. Both Aero and Space Power Systems need to:

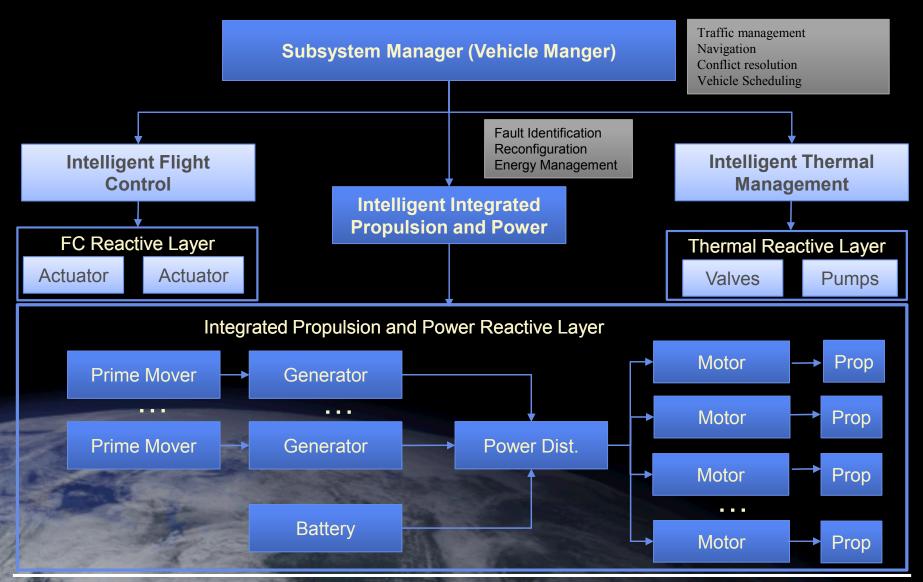
- Function autonomously for extended periods of time
- Manage distributed energy resources
- Manage loads over constrained capacity and time horizons
- Fault management
 - Guarantee that the network is safely managed
 - Detect, isolate, reconfigure and accommodate faults







Hybrid-Electric Architecture



Wrap-up



- We need Intelligent Power Systems for long term operation far from earth
- Initial autonomous power controller using real-time simulations and hardware in the loop has been demonstrated for simplified hardware configuration.



 Technology to operate proposed deep space exploration vehicles can be extended for use with Hybrid Electric Airplanes





Questions?

